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ARTICLE

# Flat-Footedness Is Not a Disadvantage for Athletic Performance in Children Aged 11 to 15 Years

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**What's Known on This Subject**

Many athletic and sport teams hold the overall opinion about the need for treatment of flexible flat feet with the sole purpose of improving athletic performance. No scientific evidence has been published confirming poor motor skills in children with flat feet.

**What This Study Adds**

Although there may still be an ongoing debate about the aims and reasons for treating FFF, this study eliminates the improvement of athletic performance as one of those reasons.

## ABSTRACT

OBJECTIVE. Because the controversy about the relation of foot morphology and foot function is still present, we find it surprising that there are no studies published dealing with motor skills and athletic performance in flat-footed school children. Our aim in this study was to determine if there is an association between the degree of foot flatness and several motor skills that are necessary for sport performance.

METHODS. The feet of 218 children aged 11 to 15 years were scanned, and the arch index was determined. The value of the arch index was corrected for the influence of age, and then the entire sample was categorized into 4 groups according to the flatness of their feet. The children were tested for eccentric-concentric contraction and hopping on a Kistler force platform, speed-coordination polygon (Newtest system), balance (3 tests), toe flexion (textile crunching), tiptoe standing angle, and repetitive leg movements. Altogether, 17 measures of athletic performance were measured.

RESULTS. No significant correlations between the arch height and 17 motor skills were found. Categorizing the sample into 4 groups did not reveal any differences between the groups in athletic performance. Also, several multivariate analysis of variance sets of multiple independent variables referring to a particular motor ability were not found to be significant. The differences were not found even after comparing only the 2 extreme groups, meaning children with very low and children with very high arches.

CONCLUSIONS. No disadvantages in sport performance originating from flat-footedness were confirmed. Children with flat and children with "normal" feet were equally successful at accomplishing all motor tests; thus, we suggest that there is no need for treatment of flexible flat feet with the sole purpose of improving athletic performance, as traditionally advised by many. *Pediatrics* 2009;123:e386–e392

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**Key Words**
flat feet, motor skills, athletic performance, children

**Abbreviations**
FFF—flexible flat feet
MANOVA—multivariate analysis of variance

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Although flexible flat feet (FFF) are a frequent observation in the clinical practice and a matter of great concern for parents, the diagnostic criteria as well as the treatment guidelines for children with flat feet remain the subject of discussion and controversy. Despite that, a remarkable number of arch supports are being constantly prescribed although the therapeutic value of such a treatment is at least doubtful if not unnecessary.[1–6]

Currently, there are no generally accepted position statements about the main reasons for treatment of FFF. It is known that the goal of any disease or condition treatment should be either preventive or curative, but published studies do not provide solid evidence that the treatment of FFF results either of these. Some believe that it is possible to change the natural history of child foot development by corrective shoes or inserts despite the lack of medically based evidence accentuated by others.[2,7–9] Nevertheless, the FFF are often treated because this condition is traditionally considered to be an underlying cause of painful feet in adulthood or a condition that may be responsible for poor motor skills and/or athletic performance.[10–11]

Motor tasks involving the lower legs activate a closed kinetic chain, with the foot being the terminal part of that chain. It is known that when a part of this chain is weak or damaged, it will affect other parts of the chain. Logically, we should ask ourselves how the different terminal segments of that kinetic chain (meaning low or high arch of the feet) influence the motor performance. According to that, if foot flatness is related to the function of the lower leg[12–17] and possible risk of sport injury,[18–20] it should also influence the motor abilities originating from the activity of the leg muscles. That is why we hypothesized that FFF should be related to children's athletic performance.

Our aim in this study was to determine if there is an association between the degree of the foot flatness and several motor skills that are necessary for sport performance.

## METHODS

This study was approved by the University of Zagreb Faculty of Kinesiology Research Ethics Board at its meeting on March 16, 2008.

The sample included 218 children attending the fifth through eighth grades of elementary school (mean age: 13.07 ± 1.24 years). Before the testing, detailed explanations of the testing procedure and parental consent forms were sent to the parents, together with the questionnaire regarding their child's engagement in organized sports activities (apart from physical education lessons in school). The questionnaire also encompassed questions about the children's health. Only children with the written consent of their parents were included in the study. Altogether, 305 questionnaires were distributed, but not all of them were filled in. The main reasons for dropout were children's recent upper respiratory tract illness, school trip at the day of testing, or absence from school on the day of testing. The children were eligible for the study if they did not have any foot or lower limb pathology or any other underlying condition. The sample of 218 tested children had a 28% dropout rate. General description parameters of the sample are presented in Table 1.

The children underwent a testing procedure encompassing measurements of foot flatness, morphologic characteristics, and motor abilities (speed, power, reaction time, balance). Computerized scans of the footprints were recorded to determine the value of the arch index. The method described by Staheli et al[21] was in this case applied on scan files, so the width of the foot in the narrowest area of the arch and the width of the heel were measured, and the former number was divided by the latter to calculate the arch index for each foot. We then calculated the mean arch index value of both feet.

The correlation analysis showed that the value of arch index was influenced by the age (Pearson $r = -0.37$), pointing to a higher number of children with flat feet among the younger subjects. If we had continued the data analysis at that point, the results would have been strongly influenced by age. That is why the following procedure was needed.

To compare the motor abilities of the children with high arch with the children with low arch, the value of the arch index had to be recalculated and freed from the influence of age. For that purpose, we used a simple regression analysis between the age and arch index and then we performed the residual analysis. This method is frequently used in situations when it is needed to equalize groups of subjects initially, so the final results would not be influenced by factors that were not of interest in a study. In this way, we obtained the new values of arch index (only residuals) that were free of the age influence (equation for residuals: arch index residuals = $1961 - 0076 \times$ age). After that procedure, the relationship of foot morphology and motor skills analyzed by using the arch index residuals as a measure of foot flatness would provide results freed of age influence.

**TABLE 1 General Description of the Sample ($N = 218$)**

| | Girls | Boys |
|---|---|---|
| Gender, % | 48.9 | 51.1 |
| Engaged in sport, % | 52 | 79 |
| Age, y | 13.04 ± 1.24 | 13.11 ± 1.25 |
| BMI, kg/m$^2$ | 20.19 ± 3.20 | 21.21 ± 3.97 |

### Motor Skills (Athletic Performance)

The tests were selected from the battery of tests usually used for testing young athletes in the Sports-Diagnostic Centre of the University of Zagreb Faculty of Kinesiology.

#### *Explosive Power: Counter Movement Jump*

This test was performed on the Kistler Quattro jump force platform. The task was to perform 3 maximal eccentric-concentric jumps with hands held at the hips. A single jump started with straight legs performing a natural flexion before the takeoff phase. Only the highest jump was recorded for which we noted the maximal jump height and the maximal force during the jump. Also, the instantaneous force was measured, which is the force at the time of transition from eccentric to concentric contraction when the power first becomes positive. This parameter was very interesting for this study, because the body weight of the subjects was subtracted.

A hopping test was also measured on the Kistler Quattro jump force platform. The subjects had to perform a series of continuous jumps with straight legs with maximal effort by using the ankles to jump, trying to keep the height. Four parameters were recorded: the average jump height, relative power, contact time, and the leg pseudo-stiffness.

#### *Toe Flexion: Textile Crunch*

The subjects had to crunch 60 cm of textile in the shortest possible time (3 attempts), performing toe flexion with heels firmly pressed to the floor.

#### *Tiptoe Standing: Plantar Flexion Angle*

The maximal angle between the floor and the lateral foot edge was measured while the subjects performed tiptoe standing (maximal active plantar flexion).

#### *Speed and Reaction Time Polygon*

To test the starting speed (5m), the reaction time, and acceleration of the subjects, the measurement system Newtest Powertimer PC system (Newtest Oy, Oulu, Finland) was used. For the purpose of this study we chose a test option called the T test. The T test is a reaction test in which the subject starts sprinting 5m on a lamp's signal

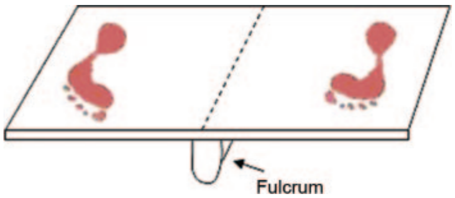


FIGURE 1
Lateral tilts test.

toward the jump mat. When the subject lands on the jump mat, a light is displayed, and the subject must run to the direction it pointed until he/she arrives at another light port. Overall time, approach time to the mat, which actually represents the starting power/speed of the subject, reaction time, and the acceleration was recorded for each subject.

### *Balance Tests*

#### *Lateral Tilts*

The subject stands on plywood balance board with feet positioned parallel to the fulcrum (pivot) of the board (Fig 1). The time stops when either of the later sides of the board touches the ground or the subject hops or otherwise loses the balance position. The best of 3 attempts is recorded.

#### *Front-Back Tilts*

The test is performed in the same manner as the lateral tilts test but with feet positioned vertical to the position of the fulcrum (pivot) of the board (Fig 2).

#### *One-Leg Balance*

The subject stands with closed eyes on 1 leg with the other leg abducted. The goal of the test is to stand in that position for 30 seconds in a minimal number of attempts. For each interruption, 1 point is added to the result.

### *Lower-Leg Repetitive Movements Test*

The subject has to make as many leg exchanges as possible over the line drawn on the floor. The test lasts 15 seconds and the number of leg exchanges is recorded. It is a test indicating neuromuscular control of the lower legs.

### Data Analysis

The data were processed by using Statistica for Windows 7.1 (Stat Soft Inc, Tulsa, OK) licensed to the Faculty of Kinesiology, University of Zagreb, and the variables were

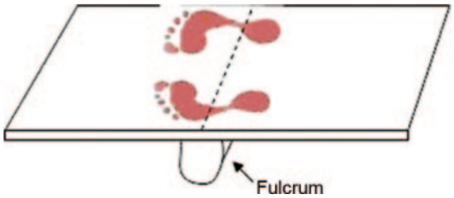


FIGURE 2
Front-back tilts test.

**TABLE 2 Correlations Between the Arch Height (Variable Arch Index Residuals) and All of the Motor Abilities Tests**

| Product-Moment Correlation | Arch Index Residuals |
|---|---|
| | Pearson's *r* |
| Repetitive movements (legs) | −0.02 |
| Height of counter movement jump | −0.02 |
| Power of counter movement jump | −0.04 |
| Force index of counter movement jump | −0.13 |
| Hopping (No. of jumps) | −0.03 |
| Hopping: average height | −0.10 |
| Hopping: average power | −0.09 |
| Hopping: time of contact | 0.07 |
| Hopping: leg pseudo-stiffness | −0.00 |
| Balance: lateral tilts | −0.10 |
| Balance: front-back tilts | 0.02 |
| Balance: closed eyes, one leg | 0.04 |
| Newtest polygon: overall time | 1.00 |
| Newtest polygon: approach time | 0.07 |
| Newtest polygon: reaction time | 0.12 |
| Newtest polygon: acceleration | −0.08 |
| Plantar flexion angle (tiptoe standing) | −0.06 |
| Toe flexion (textile crunching) | 0.05 |

None of the correlations were significant.

tested for normality of distribution by using a Shapiro-Wilk W test. To test the differences between the groups, the discriminant analysis and several multivariate analysis of variance (MANOVA) sets of independent variables were performed, as well as Student's *t* test for independent samples. MANOVA was used to test hypotheses regarding the effect of 1 or more independent variables (eg, foot flatness) on 2 or more dependent variables (eg, motor skills).

## RESULTS

### Correlations Analysis Between the Arch Height Motor Abilities

In the first step of the data analysis, the data were tested for possible correlations between the arch height (variable arch index residuals) and all of the motor abilities tests. There was no significant correlation found between foot flatness and athletic performance (Table 2).

### Controlling for Possible Differences Between the Groups According to Age, Gender, and Participation in Sport Activities

In the second step, we divided the sample into 4 groups according to the mean value or arch index residuals (Table 3): group 1 (nonflat feet): subjects below the 25th percentile; group 2: subjects between the 25th and 50th percentiles; group 3: subjects between the 50th and 75th percentiles; and group 4 (very flat feet): subjects above the 75th percentile.

As the groups were divided according to percentile values they were, of course, significantly different in values of arch index (Table 3).

Before comparison of the groups according to their athletic performance, we had to establish whether the groups differed according to age, gender, and participation in sport activities, because that would have influenced our results. By using MANOVA (Fig 3), we found

**TABLE 3** **Arch Index and Arch Index Residuals in 4 Groups With the Significance Level for Each Variable Tested by MANOVA**

| | Arch Index (Determined From Plantar Scan) | Arch Index Residuals |
|---|---|---|
| Group 1 ($n = 44$) | 0.6049 ± 0.018 | −0.3464 ± 0.013 |
| Group 2 ($n = 63$) | 0.8716 ± 0.015 | −0.0675 ± 0.011 |
| Group 3 ($n = 62$) | 1.0756 ± 0.016 | 0.0877 ± 0.026 |
| Group 4 ($n = 49$) | 1.2293 ± 0.017 | 0.2878 ± 0.012 |
| *P* | .0000 | .0000 |

Values shown are the mean ± SE.

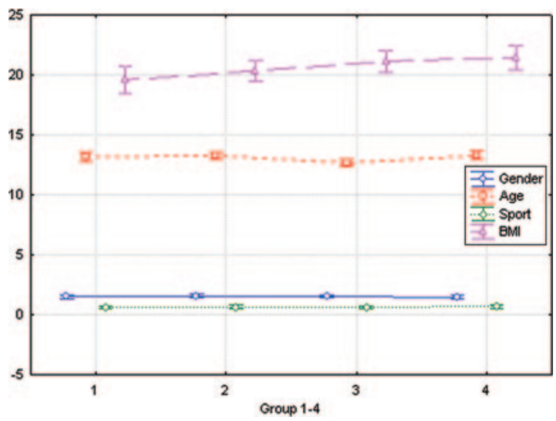


FIGURE 3
MANOVA results. The groups did not differ in age, gender, BMI, and sport activities participation (Wilks' $\lambda = .90929$; $F_{12,550.61} = 1.6792$; $P = .6767$).

that the groups did not differ according to age, gender, and participation in sport activities, which was a very important precondition for comparison of their athletic performance.

### Testing the Differences in Athletic Performance Among the 4 Groups Divided According to the Degree of Flat-Footedness

The absence of the aforementioned differences (Fig 3) enabled us to continue with the study. The differences in athletic performance among the groups were then tested by using discriminant analysis (Table 4). Discriminant analysis is used to determine which variables (if any) discriminate significantly between 2 or more naturally occurring groups.

Obviously, the discriminant analysis involving all motor tests failed to determine the differences between the groups, so according to that we can assume that the groups are very similar in athletic performance.

To test for differences with fewer variables in the model, MANOVA was used. Figures 4 to 8 reveal that the groups did not differ in any of the measured tests, so the subjects who were flat footed, normal footed, and high-arched performed almost equally in all tasks.

**TABLE 4** **The Results of the Discriminant Analysis Showing No Significant Discriminant Factor**

| | Eigen Value | Canonical | Wilks' $\lambda$ | $\chi^2$ | *df* | *P* |
|---|---|---|---|---|---|---|
| 0 | 0.1376 | 0.3478 | 0.7685 | 53.333 | 51 | .3846 |
| 1 | 0.0803 | 0.2726 | 0.8742 | 27.232 | 32 | .7068 |
| 2 | 0.0590 | 0.2359 | 0.9443 | 11.600 | 15 | .7090 |

Number of variables in the model: 17; Wilks' $\lambda$: 0.768; $\sim F_{51,578} = 1.0497$; $P < .3858$; $\chi^2$ tests with successive roots removed. *df* indicates degrees of freedom.

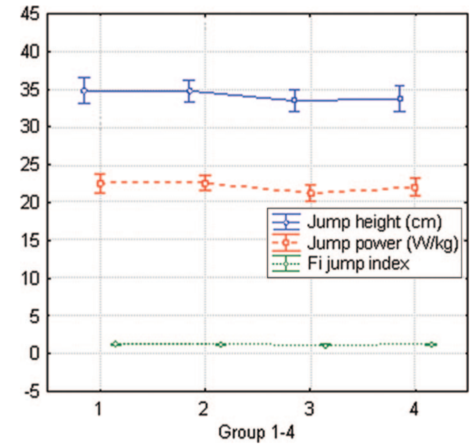


FIGURE 4
MANOVA results for counter movement jump (Wilks' $\lambda = .96571$; $F_{9,523.4} = 0.83985$; $P = .57958$).

### Searching for Differences in Athletic Performance Between the 2 Groups of Extreme Counterparts

In the final step, we compared only the extreme counterparts: group 1 with the least flat feet and group 4 with the flattest feet. A Student's *t* test for independent samples was used to compare the means of motor skills variables in the 2 groups. No statistically significant differences in sport-related motor performance originating from foot flatness were found between those 2 groups (Table 5).

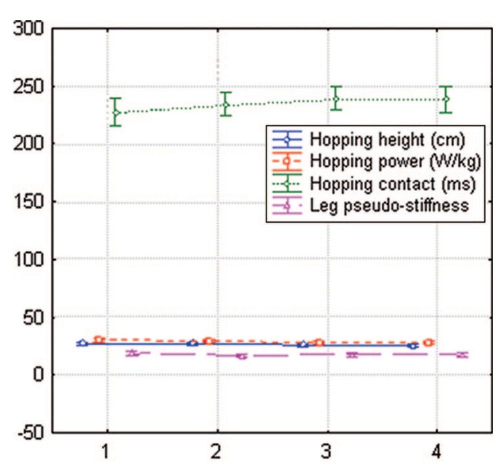


FIGURE 5
MANOVA results for hopping test (Wilks' $\lambda = .95042$; $F_{12,566.48} = 0.91615$; $P = .53027$).

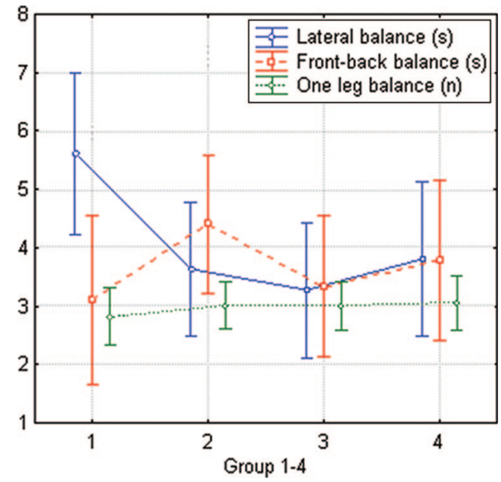


FIGURE 6
MANOVA results for balance tests (Wilks' $\lambda$ = .95362; $F_{9,523.4}$ = 1.1460; $P$ = .32816).

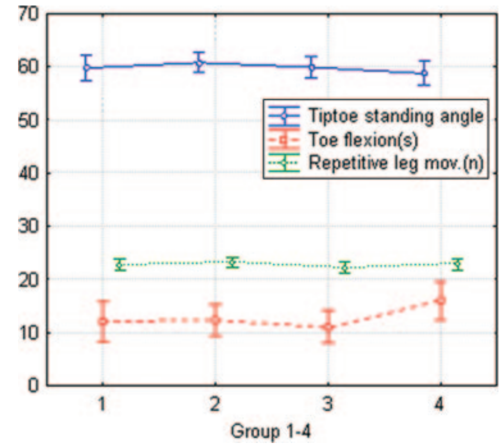


FIGURE 8
MANOVA results for Newtest speed-coordination-reaction time polygon (Wilks' $\lambda$ = .96067; $F_{9,506.37}$ = .93533; $P$ = .49377).

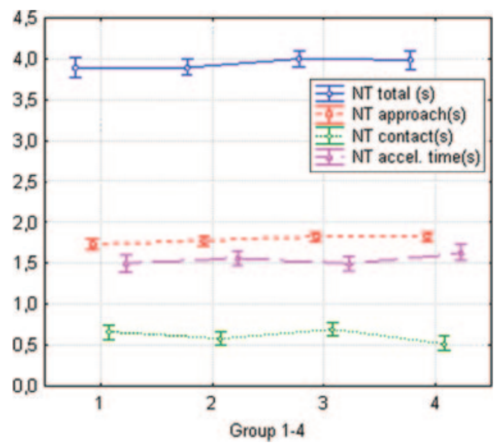


FIGURE 7
MANOVA results for Newtest speed-coordination-reaction time polygon (Wilks' $\lambda$ = .91578; $F_{12,566.48}$ = 1.5961; $P$ = .08849).

## DISCUSSION

We determined that the main finding of this study was that there were no determined differences in athletic performance among children aged 11 to 15 years who had flat or "normal" feet.

To our knowledge, the only published study dealing with low-arched feet and motor skills is a study by Lin et al,[10] who claimed poorer performance in children with FFF. We strongly believe that this study stigmatizes children with flat feet. There are few main differences between this and our study. However, their study tested preschool children whose arch heights were determined only visually. Also, the selected motor skills in that study are not essential for athletic/sport performance. According to our results, measured athletic performance in all groups was similar and did not depend on foot morphology, as no significant influence of foot flatness and motor abilities was found. All correlations were extremely low, not pointing to any possible relations between the arch index (corrected for the influence of age) and 17 motor test performances including speed, explosive power, reaction time, balance, and repetitive movements of the lower legs measured by standardized tests for testing of athletes usually used in our human performance laboratory. Even comparing only the extremes did not provide different results, and we were still unable to identify the differences in motor skills.

For some reason, traditionally, flat-footedness is related to some kind of disability: "children who have flexible flat foot are often noted to be slow in running or in performing athletic skills" or "people with low-arch feet were often assumed to be inefficient in foot skills and to be predisposed to injuries of the lower extremities, which led to the exclusion of low-arch soldiers from regular service in some armed forces. . . ."[11] It may seem that the results of our study contribute even more to the overall controversy about the functionality of flat feet and the significance and clinical relevance of flat foot morphology, because our findings do not support the aforementioned popular thesis.

It is very important to stress the fact that in our study the values of arch index were corrected for the influence of age. As previously established,[21,22] arch height is strongly influenced by age even in coherent age groups, so the use of corrected arch index values in our study enabled the comparison of the groups strictly according to their motor skills. Also, the correlation between obesity and arch height was established earlier, because obese children tend to have flatter feet.[3,23–24] As known, obese children may have poorer performance,[25–27] so that was one of the factors we had to keep in mind and that may have influenced the motor skills results in our study. As no significant differences in BMI were found between the groups (Fig 3), we can say that that the reported results in athletic performance were not influenced by obesity.

Taking into consideration the prevalence of flat-footedness in children, it is surprising that only a handful of investigations were conducted to functionally evaluate the flat foot, especially because of the generally accepted opinion and speculation that FFF might contribute to lower leg function impairment. The studies that do exist

**TABLE 5** **The Results of the Student's *t* Test for Independent Samples Showing No Statistically Significant Differences in Any of the Measured Variables**

| | Group 1 | Group 4 | *t* | F Ratio Variance | *P* |
|---|---|---|---|---|---|
| | Nonflat Feet (<25th Percentile), Mean ± SD | Flat Feet (>75th Percentile), Mean ± SD | | | |
| Foot flatness | | | | | |
| Arch index residuals | −0.346 | 0.287 | −27.93 | 1.031 | .000[a] |
| Motor abilities | | | | | |
| Jump height, cm | 34.80 ± 6.21 | 33.74 ± 5.90 | 0.848 | 1.11 | .399 |
| Jump power, W/kg | 22.54 ± 4.44 | 22.08 ± 4.35 | 0.505 | 1.04 | .615 |
| Fi jump index | 1.30 ± 0.34 | 1.23 ± 0.26 | 1.128 | 1.70 | .262 |
| Hopping height, cm | 27.23 ± 4.66 | 25.86 ± 4.28 | 1.482 | 1.18 | .148 |
| Hopping power, W/kg | 29.83 ± 5.88 | 28.15 ± 6.12 | 1.339 | 1.08 | .184 |
| Hopping contact, ms | 227.18 ± 28.34 | 238.51 ± 49.97 | −1.324 | 3.11 | .189 |
| Leg pseudo-stiffness | 18.44 ± 7.18 | 17.41 ± 4.70 | 0.831 | 2.33 | .408 |
| Lateral balance, s | 5.61 ± 9.52 | 3.81 ± 2.33 | 1.283 | 16.64 | .203 |
| Front-back balance, s | 3.11 ± 1.58 | 3.78 ± 4.13 | −1.020 | 6.84 | .311 |
| One-leg balance, *n* | 2.82 ± 1.56 | 3.06 ± 1.48 | −0.772 | 1.11 | .442 |
| NT total, s | 3.89 ± 0.36 | 3.98 ± 0.38 | −1.239 | 1.15 | .219 |
| NT approach, s | 1.73 ± 0.22 | 1.82 ± 0.27 | −1.765 | 1.53 | .081 |
| NT contact, s | 0.67 ± 0.27 | 0.62 ± 0.71 | 0.459 | 7.00 | .648 |
| NT acceler, s | 1.50 ± 0.32 | 1.63 ± 0.38 | −1.842 | 1.37 | .069 |
| Tiptoe standing angle | 59.89 ± 6.86 | 58.71 ± 7.77 | 0.767 | 1.28 | .445 |
| Toe flexion, s | 12.07 ± 12.14 | 15.97 ± 13.73 | −1.415 | 1.28 | .161 |
| Repetitive leg movement, *n* | 22.73 ± 6.21 | 22.76 ± 4.47 | −0.032 | 1.40 | .974 |

Fi indicates force index (instantaneous force) on jump platform; NT approach, start time on Newtest polygon; NT acceler, time measured after the lamp signal on Newtest polygon.
[a] Significance at $P < .001$.

deal with clinical analysis of gait or posture and describe various kinematical and kinetic parameters.[12,13,15–17] No attempts were made to evaluate the function of flat feet in regard to the motor abilities that are a precondition for successful sport performance. Also, none of the studies compared the subjects while performing at maximal effort (strength, power, or speed tests).

Staheli[7] stated that the success of orthotic treatment for FFF is based on the natural history of the disease alone, and, because of this fact, corrective insoles may be counterproductive. Furthermore, according to him, such treatments are unnecessary, ineffective, harmful, expensive, uncomfortable, embarrassing for the child, and are associated with lowered self-esteem in adult life. Still, there are other studies that do not support such an extreme opinion, especially those studies that relate FFF to acute or overuse musculoskeletal injuries.

For example, according to the article investigating the aforementioned problem in military recruits, the significant relationship between pes planus and number of injuries sustained over a 4-year period at West Point was established.[18] Also, a prospective study of injuries in 83 female infantry recruits identified the low arch of the foot as a possible risk factor for ankle sprain.[28]

Now we come to the controversy: in the controlled study that followed a rigorous 12-week training program among 246 US Army infantry trainees, the individuals low arches were found to have 3 times lower risk of injury than the recruits with an average arch height, and 6.1 times lower risk than the subjects with high arch.[19] Giladi et al[29] stated that flat feet may also be a protective factor for overuse injury, because some evidence was provided pointing to the lower risk of stress fractures in subjects with flat feet compared with normal- or high-arched individuals. To continue the discordance, Taunton et al[30] claimed that there is no significant effect of arch height on injury rate, whereas some found the opposite and defined the flat foot as a possible risk factor for stress fractures.[20,31]

Williams et al[32] offered an explanation for this apparent contradiction: high-arched and low-arched feet might be associated with different lower extremity injuries in runners. The most common injuries in the high-arched group were plantar fasciitis, lateral ankle sprain, and iliotibial band friction syndrome. Low-arched runners reported general knee pain, patellar tendinitis, and plantar fasciitis. In both groups, metatarsal stress fractures were diagnosed.

Obviously, it is very hard to decide whether flat foot is a physiologic adaptation or a pathologic condition. Therefore, similar to Bertani et al,[17] we believe that the decision whether to treat FFF is often difficult, because there is a lack of objective criteria to assess possible functional abnormalities of the lower leg/foot/ankle complex.

Although we believe that FFF is not related to any kind of leg disability, and although many claim that the treatments of FFF are not effective,[1,2,6,7] the relationship between foot flatness and acute or overuse musculoskeletal injury still remains unclear. In our opinion, if the foot morphology itself does not affect motor skills it might not affect injury patterns either. However, if that influence does exists, it is perhaps caused by different rotational forces that dominate in the lower leg and foot during the stance phase of gait dependent on the various foot structures.[11,15] Similarly, Akcali et al[33] speculated that the abnormal external tibial torsion could eventually change the benign nature of FFF.

## CONCLUSIONS

As already stated by Wenger et al,[34] it is not easy to solve the controversy about flat-footedness by only 1 study. Our findings are just a contribution to the overall understanding of the functionality of flat feet and possibly related problems. According to our results, no disadvantages for sport performance originating from flat-footedness were confirmed. It seems that foot flatness does not affect lower leg motor abilities, so accordingly, the application of standard corrective insoles with the purpose to improve athletic performance in children aged 11 to 15 years, as traditionally advised by many, is at least questionable and maybe even not advisable.


## ACKNOWLEDGMENT

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**Flat-Footedness Is Not a Disadvantage for Athletic Performance in Children Aged 11 to 15 Years**

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